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REPORT R-1668

UNITED STATES ARMY

FRANKFORD ARSENAL

PROPERTIES AND WORKING CHARACTERISTICS OF
CAST CELLULAR AND COMPOSITE MATERIALS

by

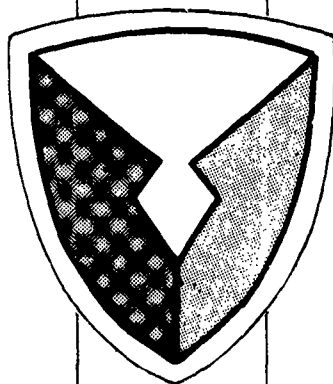
L. POLONSKY
and
S. LIPSON

OMS Code 5026.11.843
DA Project 5B93-32-008

February 1963

PHILADELPHIA 37, PA.

REPORT R-1668



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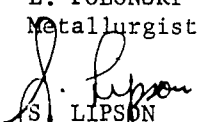
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DA Project 5B93-32-008

Prepared by:


L. POLONSKY
Metallurgist

S. LIPSON
Metallurgist

Reviewed by:


A. L. JAMIESON
Deputy Director
Pitman-Dunn Institute
for Research

Approved by:


C. C. FAWCETT
Technical Director
Research & Development Group

for

GEORGE H. PIERRE, Jr.,
Colonel, Ordnance Corps
Commanding

FRANKFORD ARSENAL
Philadelphia 37, Pa.

February 1963

ABSTRACT

A study was conducted to: (1) produce a variety of nonferrous cellular and composite materials; (2) subject certain composite materials to swaging, forging, and extrusion; (3) determine certain physical and mechanical properties of these materials; and (4) predict the characteristics of untried composite systems from these properties.

This study was exploratory in nature and involved, for the most part, simple combinations of pure metals. The properties of the component phases of the systems studied were determined in the cellular and solid form. The properties of the cast composites showed that, where the difference between the strength of the component phases was not excessive (the stronger phase being no more than four times stronger than the weaker), the properties of the composite system could be predicted on the basis of a knowledge of the characteristics of the component phases.

Some of this material was subjected to working by a swaging process. This improved the strength of the composite materials, but the limited reduction (three diameters) was apparently insufficient to bond the components effectively. Several tests conducted with extruded metal-salt composites showed promise. The salt phase could be made to deform without fracture and the cell geometry was converted from equiaxed to slender voids which were 1000 times longer than their diameter.

Potential application for these materials is discussed. Future work will be restricted to study of the characteristics of extruded composite metal and metal-nonmetal systems.

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PART I - COMPOSITE METAL STRUCTURES

INTRODUCTION

A method for production of porous metal bodies, where the pores or cells are completely interconnecting, was described in an earlier report.⁽¹⁾ Briefly, the method consists of filling a refractory mold with a soluble refractory aggregate, thermally treating the mold and casting the metal so that it will infiltrate the spaces between the particles of the aggregate. The aggregate may then be leached away to leave a porous structure which is called "cellular" metal.

As an extension of the earlier work, this investigation was intended to produce a favorable orientation of the voids by working of the cast material. A second objective of this study was to use the cellular metal skeleton as a base for production of composite metallic materials. This can be accomplished by secondary infiltration of the cellular skeleton with a material selected to impart certain desirable properties to the composite structure. It was anticipated that by suitable working of the cast composite, a metallurgical bond might be established between the components. The working operation would also serve to convert both components into long filaments held together by a metallurgical bond. This technique would permit the use of a hard, strong material as the secondary phase because it would be present as slender filaments which should be capable of flexing without fracture. In addition, the secondary phase would represent two-thirds of the volume and, therefore, would significantly contribute to the overall strength of the composite. A third objective of this study was to evaluate the characteristics of cast composite materials in which the primary component would be a granular nonsoluble metallic or non-metallic aggregate which would be infiltrated with aluminum. This composite would be evaluated both in the as-cast condition and after working. A final objective was to determine whether the properties of composite materials could be predicted from the known properties of the component alloys.

It should be noted that secondary infiltration may be used to combine materials into coherent composite structures that are beyond the scope of conventional alloying or powder metallurgy methods. The components of these composites would be present as two separate but individually continuous phases in the structure.

(1) Polonsky, L. and Lipson, S., "A New Type of Lightweight Cellular Material," Frankford Arsenal Technical Report R-1534, April 1960.

METHODS AND MATERIALS

Preparation of Samples

The composite samples were produced as 1.5-inch diameter billets, 6 inches long. Figure 1 is a schematic illustration of the three types of molds used for sample preparations. The molds were 2-inch inside diameter by 8-inch long steel pipe, lined with plaster bonded investment material. A 4-inch long similarly lined pipe, which acted as a riser, was positioned over the mold. The molds were prepared by heating to the vicinity of the liquidus temperature of the metal to be cast. The riser sleeves were prepared by heating to the pouring temperature of the metal.

The cellular aluminum skeleton was cast (primary infiltration) as shown in Figure 1A. After leaching, the skeleton was replaced in the mold (Figure 1B), pinned to position it firmly, and the secondary infiltration operation was performed. Where casting with a solid sheath was desired, the mold diameter was increased to 1-3/4 inches and the cellular skeleton centered in the mold as shown in Figure 1C.

The metal skeletons used as a base for the secondary infiltration were all prepared by a primary infiltration of a 20-mesh (0.033 inch average diameter) soluble aggregate (NaCl). These skeletons were either commercially pure aluminum or 40E aluminum alloy. The secondary infiltrants were lead, tin, zinc, #43 aluminum alloy, and eutectic aluminum-copper (Al-33% Cu).

Cellular and solid castings were also made with the materials used as primary and secondary infiltrants for the purpose of determining the properties of the component elements of the composites in both cellular and solid form.

In addition, a number of composites were made by infiltration of nonsoluble aggregates. These aggregates consisted of graphite and Kanamite. The latter is a lightweight proprietary ceramic material in the form of hollow spheres. Its bulk density ranges between 0.3 and 0.4 g/cc. The same primary alloys were used for these composites as were employed in the metal-metal systems.

Experience has demonstrated that the optimum mold and pouring temperatures fall into a comparatively narrow range. The exact temperature selected is dependent upon such factors as whether the infiltration is primary or secondary and on the cell structure, mold dimensions, pressure casting technique, and solidification practice.

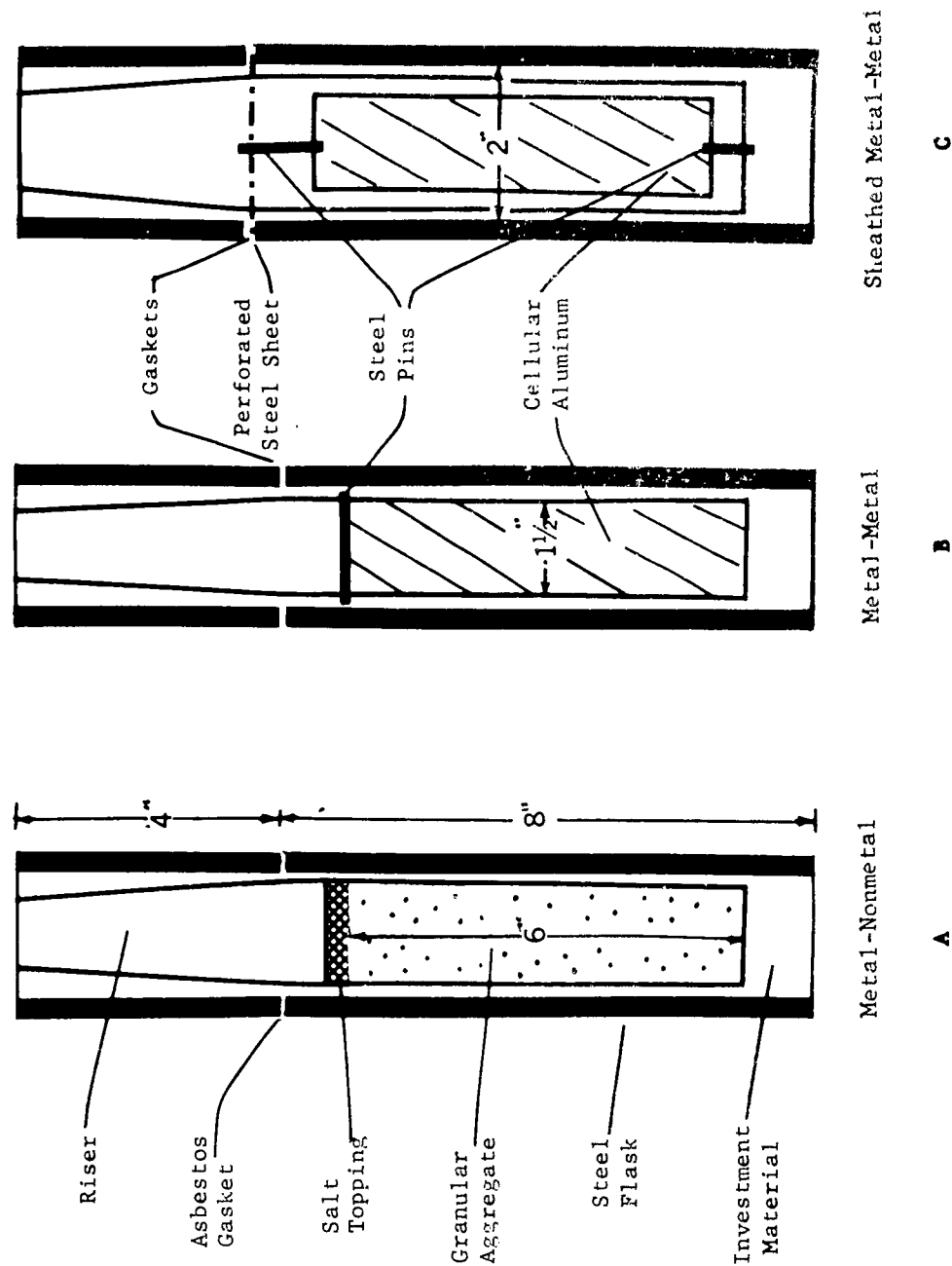


Figure 1. Molds for Composite Material.

Table I lists the conditions under which the sample cellular castings were prepared. The secondary infiltration was accomplished under substantially the same conditions as were used for producing the cellular skeleton, except for infiltration temperatures.

Working Methods

In order to realize the maximum strength from a composite metal-metal system, it is necessary to establish a coherent structure. This is accomplished by achieving metallurgical bonding between the phases. During the secondary infiltration of the primary skeleton, it is generally best to avoid wetting and alloying. If casting conditions were so arranged that alloying occurred, it would very likely be difficult to control in such a way that the geometry of the system would be preserved. For this reason the more logical approach was to achieve metallurgical bonding through hot working of the composite structure.

The temperatures used for hot working were selected high enough so that the hard phase would flow readily. Press forging in grooved dies provided the necessary constraint and slow deformation for control of the work in the critical initial reduction. The 2S Al-AlCu composite was most sensitive to temperature and had to be press forged all the way in heated dies. Other materials, such as Al-Zn, could be finished by working the heated stock in cold swaging dies after effective initial breakdown. All composite rods were reduced approximately from 1-1/2 inches to 1/2 inch in diameter, a cross-sectional area reduction of nine times.

It was not possible to press forge the metal-salt composites under any of the conditions tested. This included metal sheathed composites such as is shown in Figure 2.

Figure 3 shows the design of the press forging dies, and Table II summarizes the working procedures used for reduction of the cast composite structures.

Testing Methods

Mechanical Tests

Compression Test - The principal test used to evaluate the mechanical strength of the cellular and composite materials was the compression test. This was done because of the simplicity of the

**TABLE I. Mold and Metal Pouring Temperatures Used
For Primary and Secondary Infiltration**

<u>Metal</u>	<u>Density*</u> <u>(g/cc)</u>	<u>Melting Range*</u> <u>(°F)</u>	<u>Infiltration Temperature (°F)</u>			
			<u>Primary</u>		<u>Secondary</u>	
			<u>Mold</u>	<u>Pouring</u>	<u>Mold</u>	<u>Pouring</u>
Aluminum						
2S	2.71	1190-1215	1250	1350	-	-
40E	2.81	1060-1140	1200	1350	1100	1180
356	2.68	1075-1130	1200	1350	1100	1180
43	2.69	1070-1165	1150	1200	1100	1180
Al-33% Cu	3.50**	779.4	1075	1100	1075	1100
Lead	11.340	618	700	850	700	850
Tin	7.298	449	550	625	550	625
Zinc	7.133	787	850	950	850	950

*Values compiled from Metals Handbook, 1948

**Value determined experimentally

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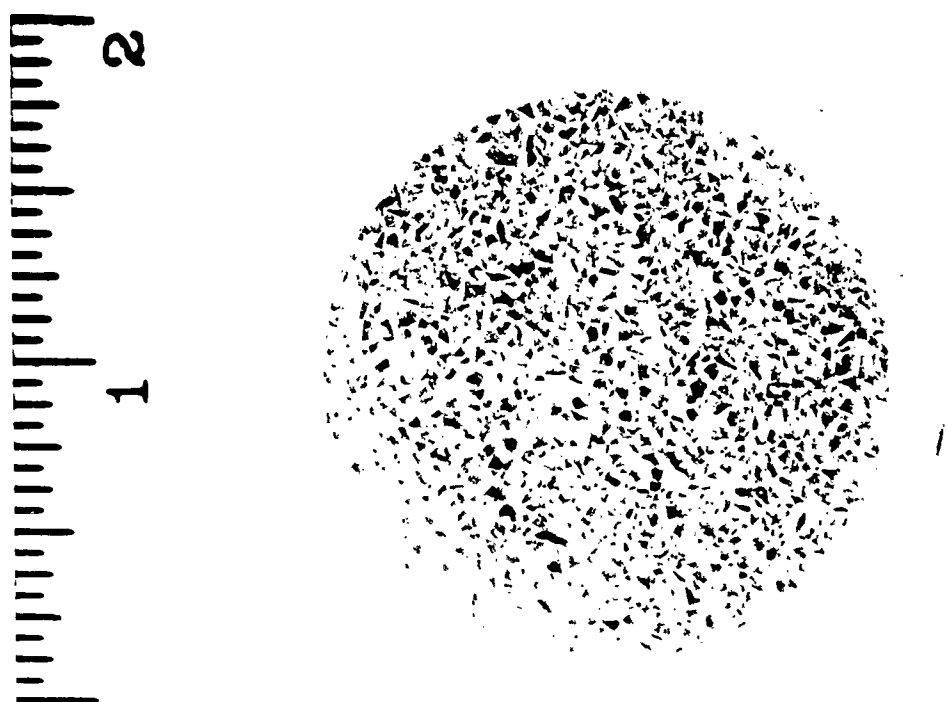


Figure 2. Cross section of Aluminum-20 mesh Salt Composite Material encased in Cast Aluminum, prior to rolling

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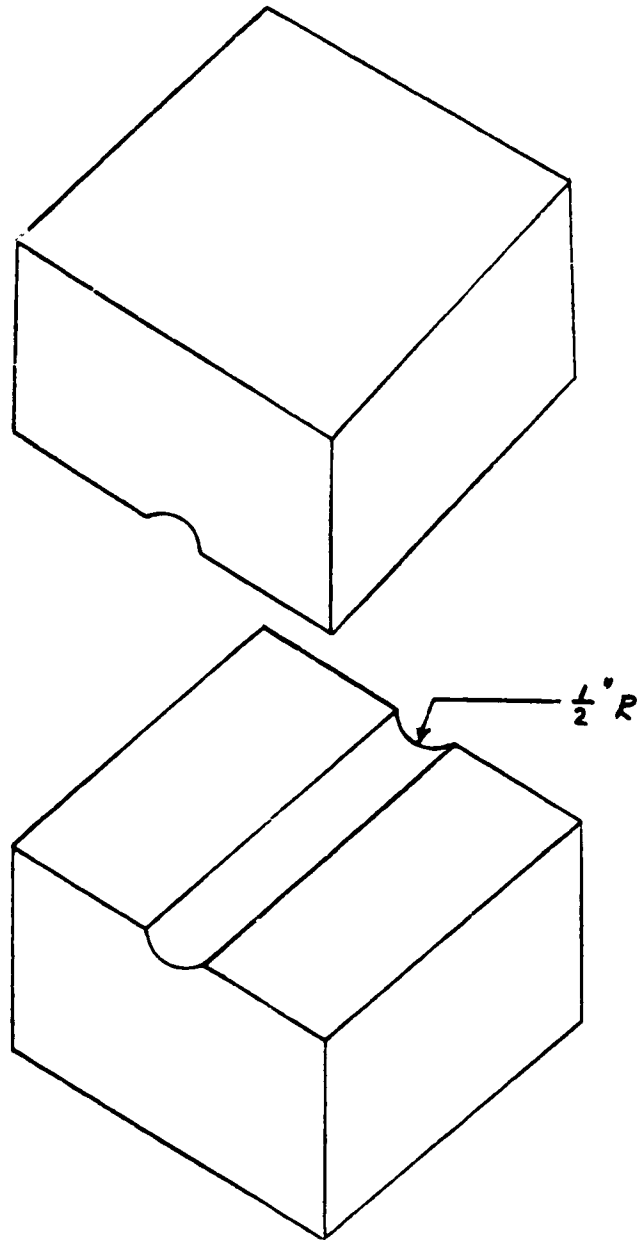


Figure 3. Round grooved Press Forging Die Halves

TABLE II. Procedure Used For Working of Cast Composites with Skeleton of 2S Aluminum

<u>Infiltrant</u>	<u>Initial Working</u>		<u>Intermediate Stock Dia. (in.)</u>	<u>Final Working</u>		<u>Final Stock Dia. (in.)</u>
	<u>Method</u>	<u>Stock and Die Temp (°F)</u>		<u>Method</u>	<u>Temperature (°F) Die Stock</u>	
Lead	Press forging	400	1-1/4	Rotary swaging	Room 400-200	5/8
Tin	Press forging	500	1-1/4	Rotary swaging	Room 300-200	1/2
Zinc	Press forging	700	1	Hammer swaging (grooved dies)	Room 700-500	5/8
Al-Cu Eutectic	Press forging	900	1	Press forging	900-750 900-800	1/2 x 5/8 (oval)
43 Al Alloy	Hammer forging	650 (stock) 400 (dies)	1	Press forging	200 200	1/2

test and the ease of specimen preparation. The specimen used for the as-cast materials was a cylinder 1.500 inches in diameter by 1.000 inch high. Since the maximum diameter of the worked material was 1/2 inch, a 0.400 inch diameter specimen was used for testing the worked materials. In order to maintain the same proportions, the height of this specimen was 0.267 inch. The compressive yield strength at 0.2 percent offset was the only measurement used.

Tensile Test - The cellular structures have an extremely small load-bearing capacity in tension, and for this reason the test was not believed to be appropriate for these materials in the cast condition. It was anticipated that the worked composite material could be expected ultimately to develop good tensile properties. Tensile testing was, therefore, confined to these worked materials, and tensile yield strength (0.2% offset), ultimate tensile strength, and percent elongation were determined. The specimen selected was the R-2 type 0.357 inch diameter bar (Federal Test Method Standard No. 151) having a gage length of 1.4 inches.

Density

Density values were obtained from measurements made on the specimens machined for the compression test. Volumes were calculated from the specimen measurements and the specimen weights in air were used to determine their apparent density.

RESULTS

As-cast Properties

The as-cast materials were classified into four groups: cellular, metal-nonmetal, metal-metal, and solid. The properties obtained were the average of three determinations of the apparent density and compressive yield strength. The strength-to-density ratios were calculated from these values.

Figure 4 graphically illustrates the data obtained with the metals in both the cellular and solid form. In general, the compressive yield strength of a material in the cellular form is approximately 10 percent of the solid. The data also show that the potential for development of high strength materials lies chiefly with a material such as the Al-Cu eutectic. In the as-cast form, this composition showed a strength-to-density ratio of almost 700,000 inches. Of course, the eutectic is brittle in the solid form.

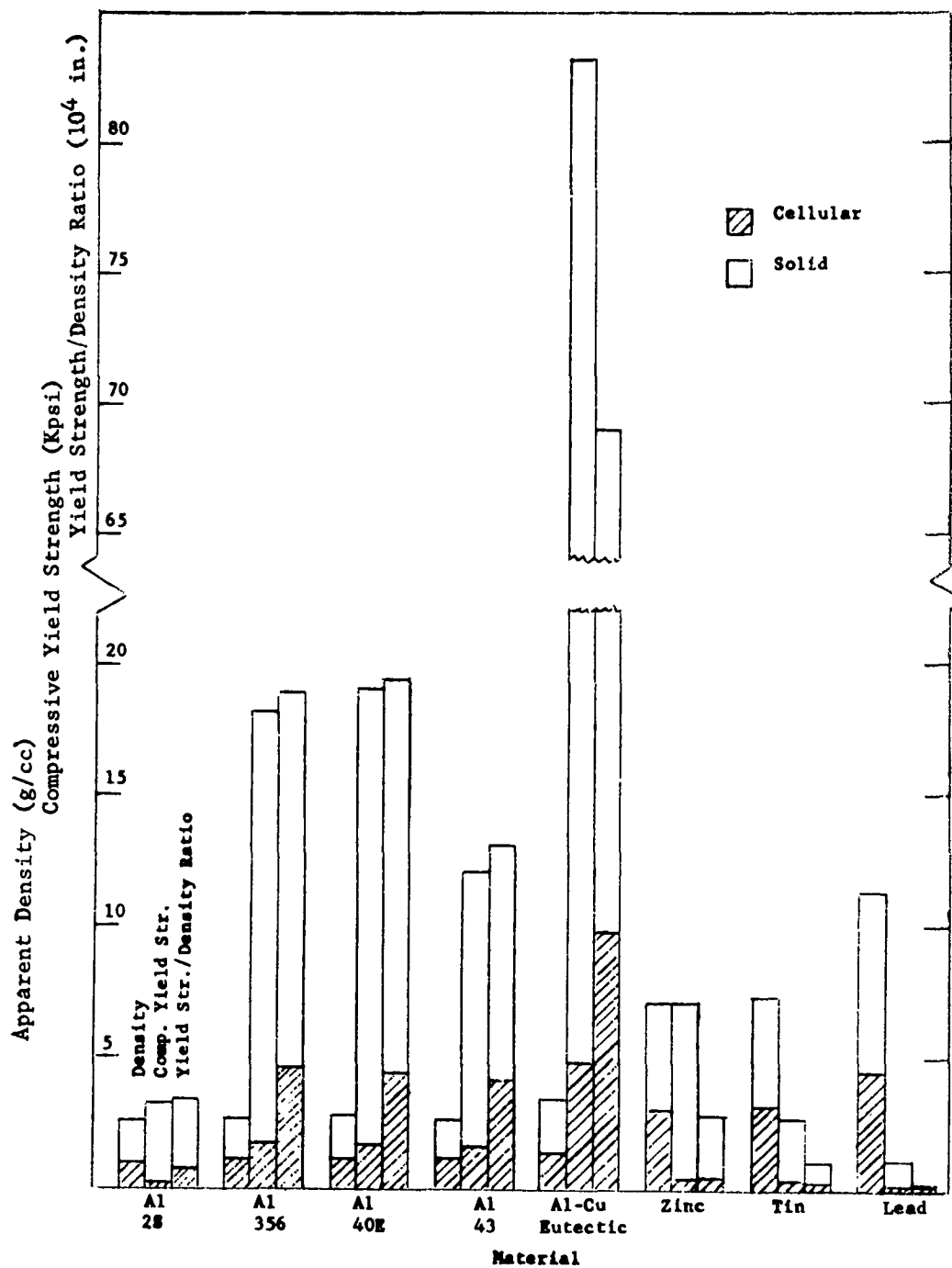


Figure 4. As-cast compressive properties of Cellular and Solid Metals

Figure 5 presents the data obtained with the metal-nonmetal composites and Figure 6, the metal-metal materials.

Wrought Properties

The wrought composites consisted of five combinations. In all instances the primary infiltrant, or cellular skeleton, was 2S aluminum. Table III lists both the tensile and compressive data obtained with these materials. The tensile values obtained with the composites containing the Al-Cu eutectic and the 43 Al alloy merit some comment. The 1.9 percent elongation obtained with the former suggests that eventually the composite technique will make it possible to realize the inherent strength of brittle materials of this type by utilizing the ductile properties of the second component. The Al-Cu eutectic by itself is extremely brittle without any measurable elongation. The data obtained with the 2S aluminum-43 aluminum composite may be compared with the following typical values for the cast 43 alloy.

<u>Form</u>	<u>Strength (psi)</u>		<u>Elongation (%)</u>
	<u>Tensile</u>	<u>Yield</u>	
Die cast	30,000	14,000	7.0
Sand cast	19,000	9,000	6.0
Permanent mold	24,000	9,000	9.0
Composite	17,500	15,200	14.7

The lower tensile strength of the composite is probably due to the lack of sufficient working to achieve effective metallurgical bonding of the components.

Figure 7 is a bar graph showing the increase in compressive yield/density ratio attributable to forging and swaging.

Metallographic Examination

The as-cast macrostructure of composite materials depends on the shape and distribution of the granules infiltrated. An aggregate of essentially cubical salt particles contains angular voids, which are approximately equiaxed. These voids are filled with metal during the infiltration process.

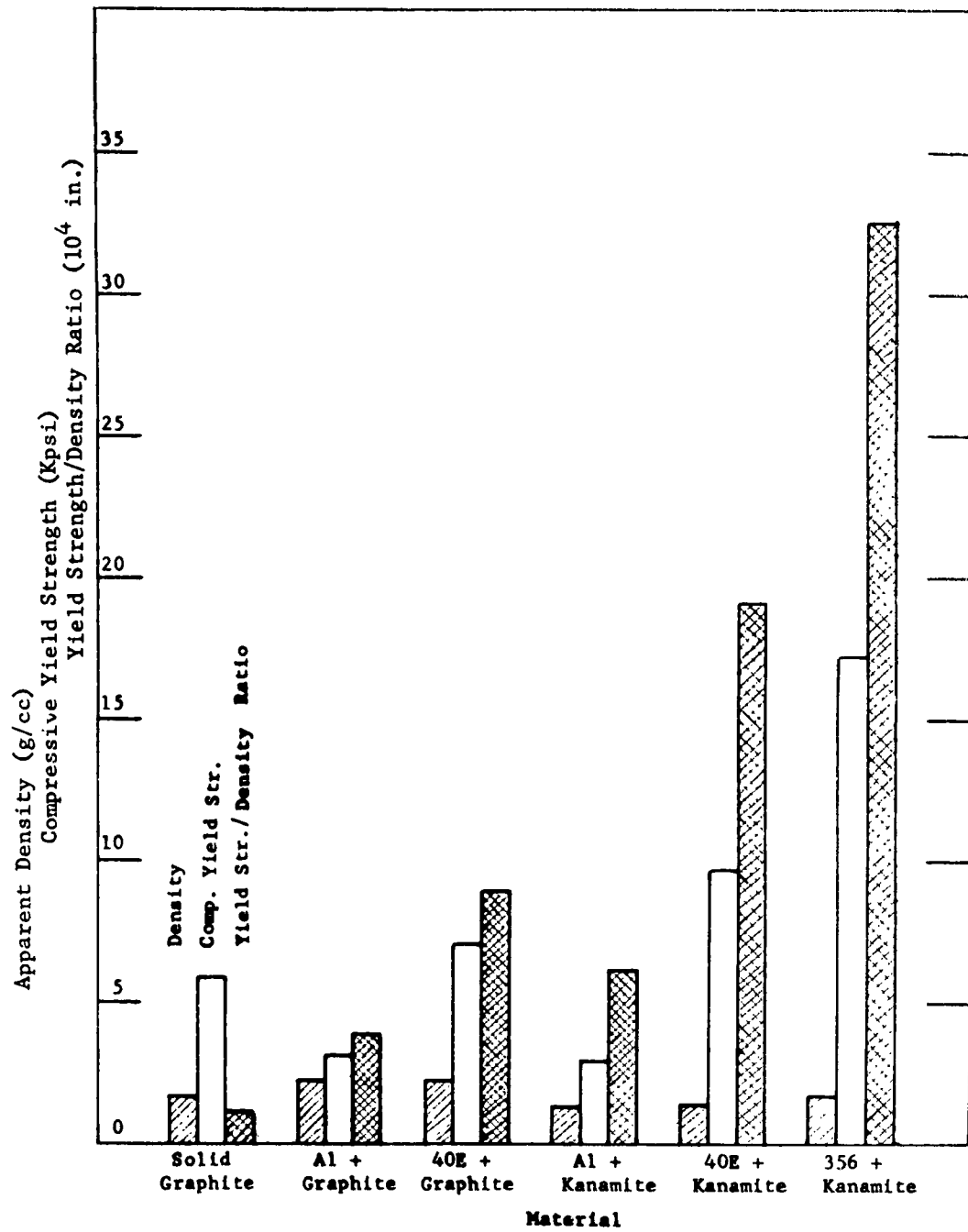


Figure 5. As-cast compressive properties of Metal-Nonmetal Composites

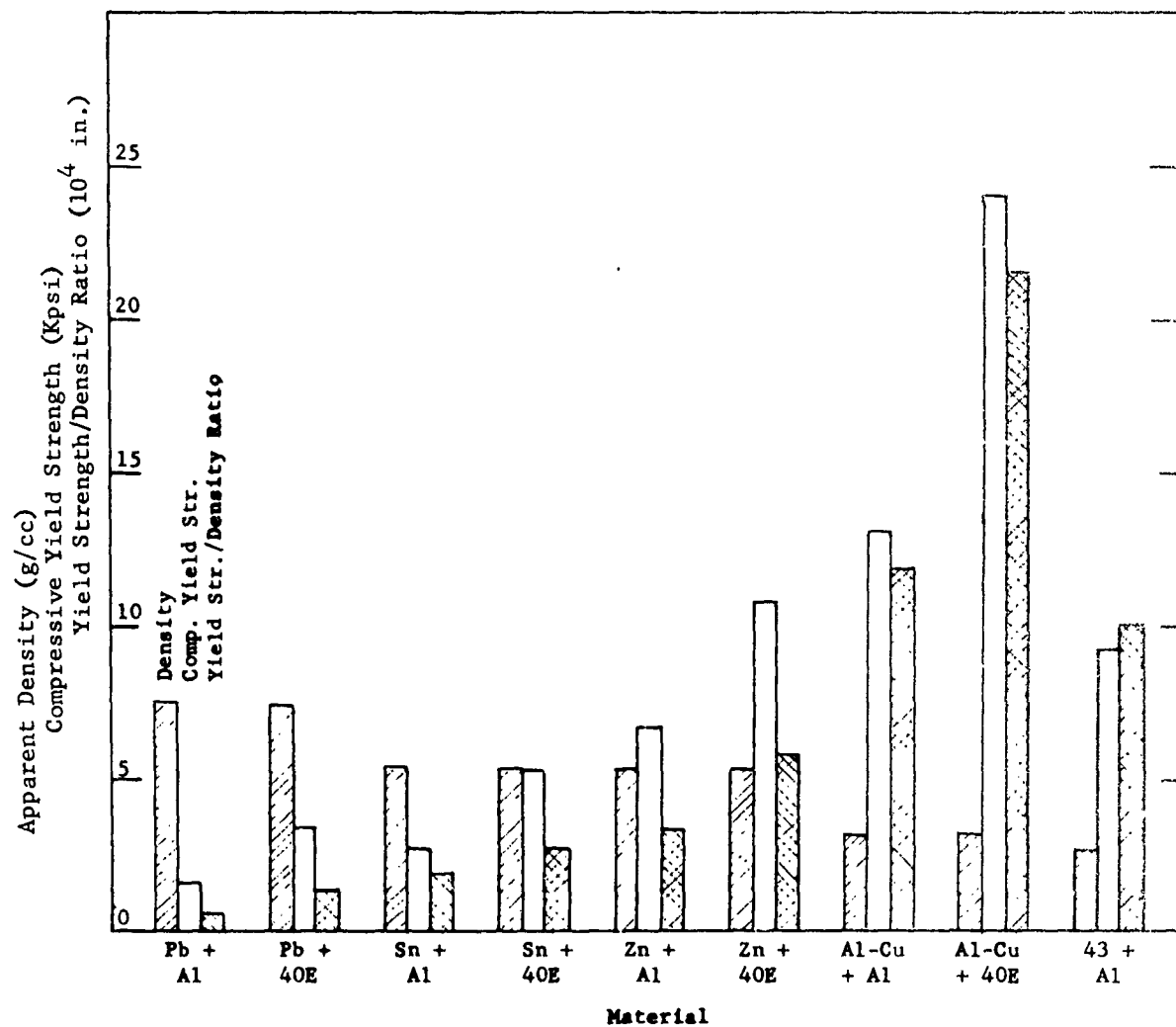


Figure 6. As-cast compressive properties of Metal-Metal Composites

TABLE III. Mechanical Properties of Wrought Metal-Metal Composites (2S Aluminum + Secondary Infiltrant)

Secondary Infiltrant	Tensile Properties					Compressive Properties		
	Density* (g/cc) (lb/in. ³)	Strength (psi)		Elongation in 1.4 in. (%)	Y.S./Density Ratio (in.)	Yield Strength 0.2% Offset (psi)	Y.S./Density Ratio (in.)	
		Yield (0.2% Offset)	Ultimate					
Lead	7.74	0.278	2,000	2,200	2.0	7,200	3,300	12,000
Tin	5.46	0.194	5,700	6,000	6.8	29,000	7,500	38,000
Zinc	5.30	0.192	10,900	14,600	15.8	56,000	14,400	74,000
Al-Cu Eutectic	3.15	0.117	18,500	24,200	1.9	179,000	25,900	228,000
43 Al Alloy	2.67	0.096	15,200	17,500	14.7	158,000	16,400	171,000

*Average of 3 samples

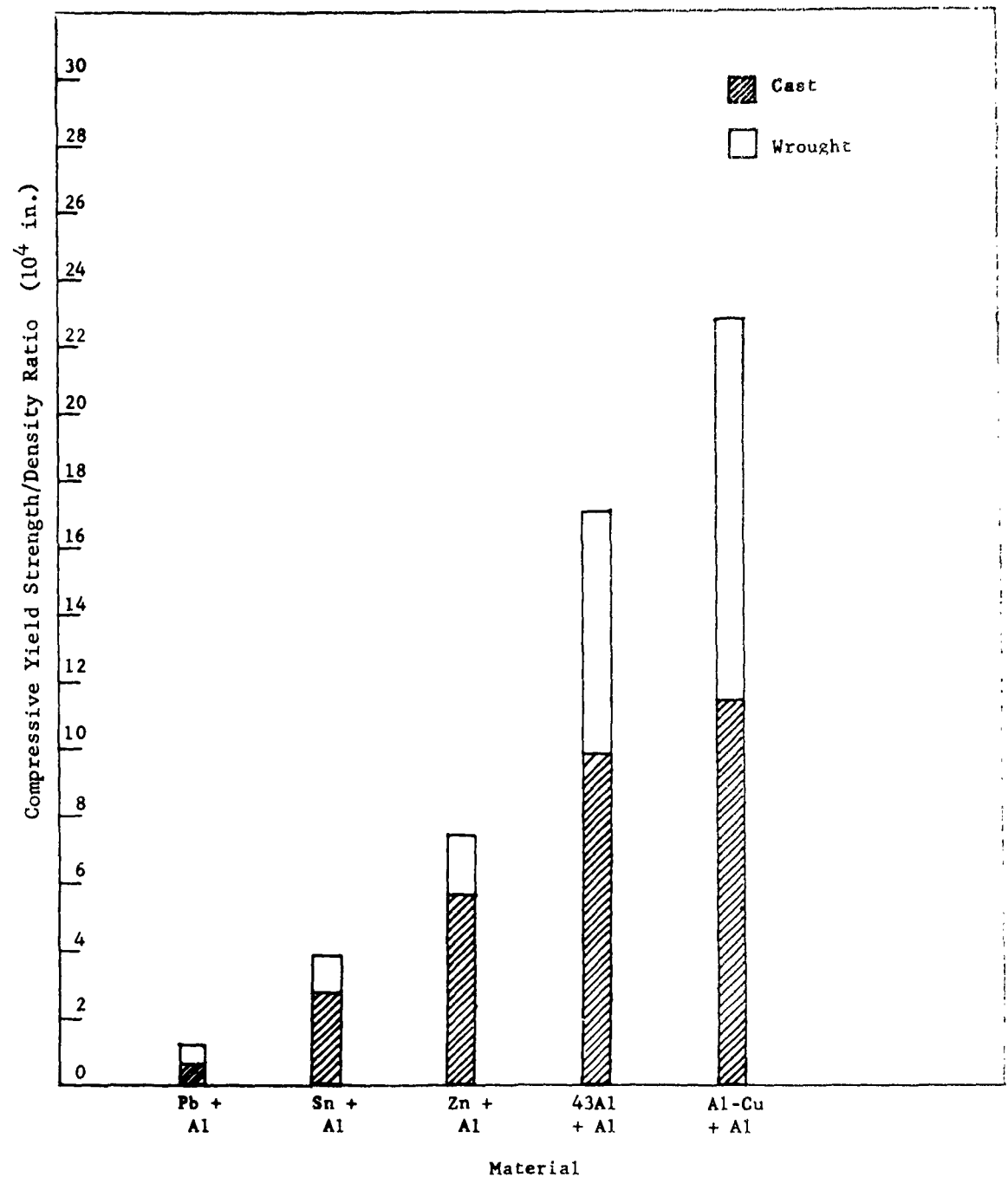


Figure 7. Effect of Working on the Compressive Yield Strength/Density Ratio of Metal-Metal Composites

It was shown in reference 1 that, with a high degree of efficiency of infiltration, the apparent density of cellular aluminum alloy of a single mesh size is 1.03 g/cc. From the density value of the solid alloy (2.68), it is possible to calculate the void volume and metal volume in the skeleton. This value was determined as 38 percent metal and 62 percent void, a ratio which is independent of mesh size, so long as it is uniform. The surface of a cross-section of a metal skeleton will have 38 percent of its area as metal and 62 percent as void.

Where secondary infiltration of the structure has been performed, 62 percent of the area will represent the secondary infiltrant. This same surface and volumetric relationship will hold after the material has been worked (Figure 8).

The microstructures of metal-metal composites shown in Figures 9 and 10 reveal a number of similarities among the several systems produced. In the as-cast condition all display typical cast structures with large grain size of both components. The corresponding wrought structures reveal elongated cells, the microconstituents of which show the directionality produced by working. The light etching phase is the 2S aluminum.

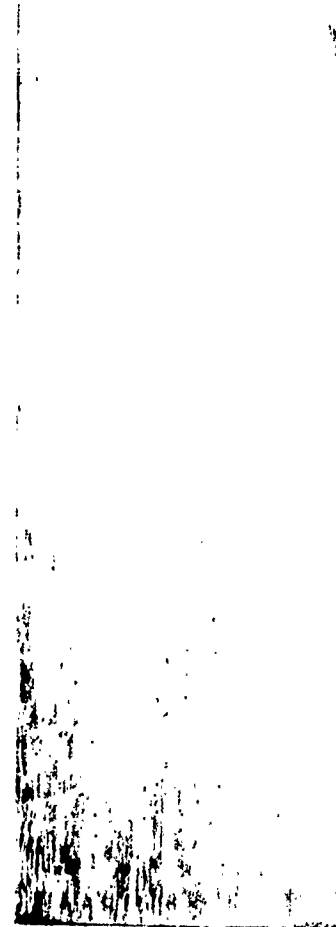
Diffusion between the components has not taken place in any of the composite systems studied, since the time at temperature was short. Metallurgical bonding, as indicated by diffusion, could therefore not be detected by microexamination. However, it is not likely that the continuity of the surface oxide film between components could be maintained with the degree of mechanical deformation applied (a 3:1 reduction in diameter).

Mechanical working also served to strengthen each structure by elongating the cells into fibers. In the case of the 2S-43 aluminum composite, the structure was further strengthened by breaking down the silicon platelets into smaller particles which have been partially spheroidized. The working treatment also increased the density of the composite materials by closing the interfacial gaps. The volume occupied by these gaps is characteristic of the solidification shrinkage of each secondary infiltrant, since the thermal expansion of the skeletal material may be considered negligible. It should be noted that there is no evidence of gross shrinkage in any of the composite systems.

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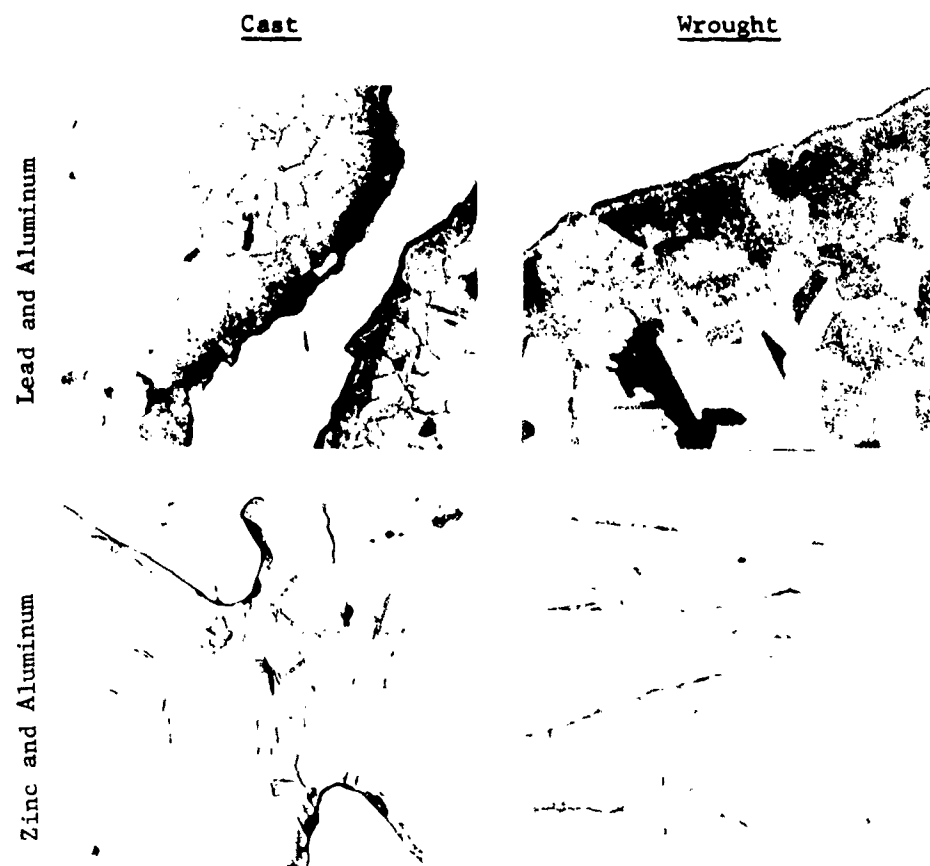
Cast



Wrought

Figure 8. Macrostructure of Zinc-Aluminum Composite Materials
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Mag: 150X

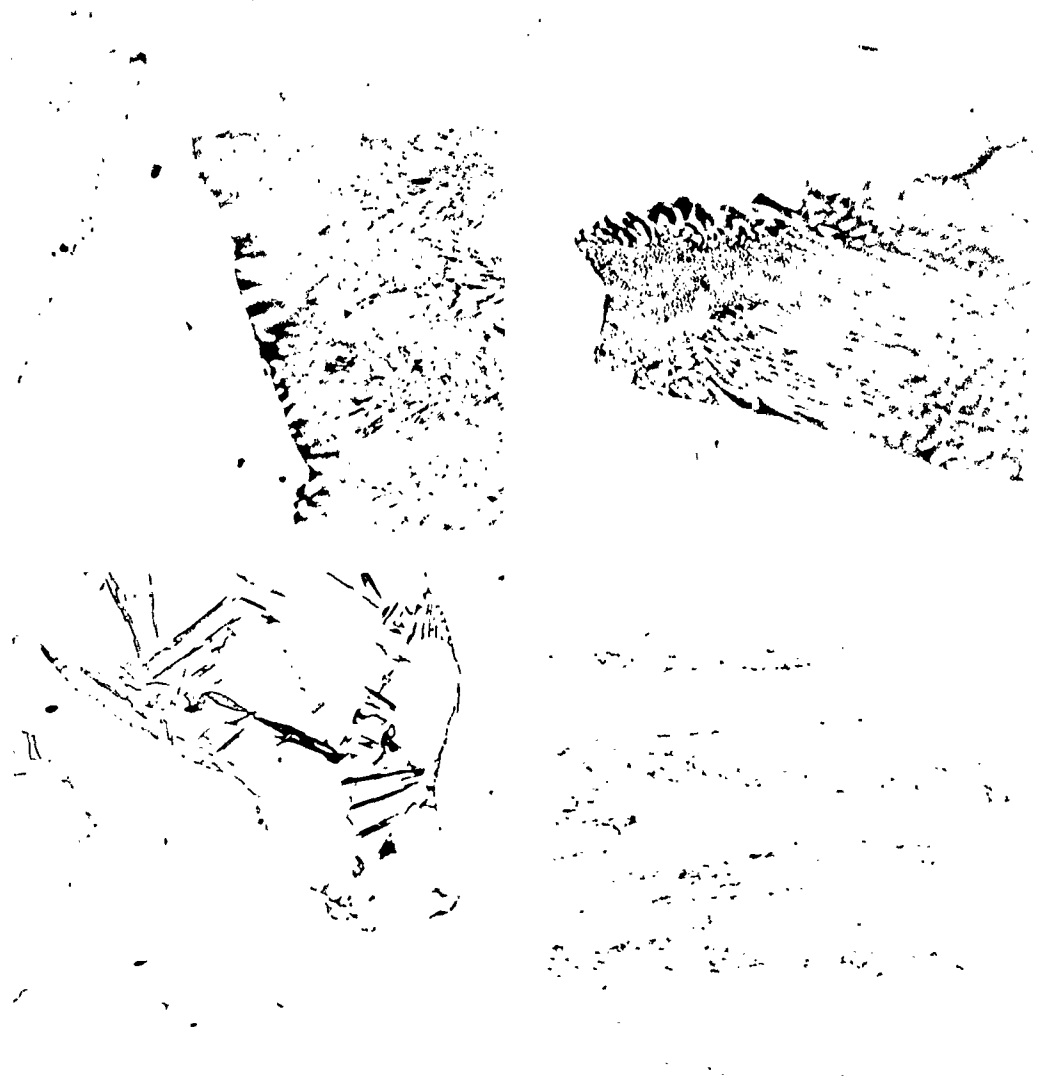
Figure 9. Microstructures of Composite Materials

Cast

Wrought

Al-Cu Eutectic and Aluminum

43 Al and Aluminum



Mag: 150X

Figure 10. Microstructures of Composite Materials

DISCUSSION

One of the objectives of this study was to determine the contribution of each of the components in a composite system toward the resulting properties of that system. An examination of the compressive yield strength data obtained with single materials and with composites composed of these materials does show that, for many of the combinations, the strength of the composite is proportional to that of the component alloys in the composite. Figure 11 is a plot of the measured compressive yield strengths versus the calculated strengths. The calculated strength is simply the sum of the strengths of each component in proportion to its relative volume in the composite; i.e., calculated strength equals 0.38 times the strength of the skeleton plus 0.62 times the strength of the secondary infiltrant. Those points which do not fall close to the theoretical line represent materials which have the largest differences between the strength of the two phases.

To better illustrate this observation, the same data are plotted in Figure 12. The ordinate represents the percentage of the calculated strength actually realized in the composite, and the abscissa the ratio of the compressive yield strengths of the component phases. This graph shows that the systems whose actual strength did not correspond with the calculated values were those where the strength ratios between the phases were more than four. As the disparity between the strength of the phases became greater, the disparity between the calculated and actual strengths of the composites also became greater. This same kind of analysis was applied to the compressive strengths measured at 10 percent deformation. These data also showed a sharp departure between the actual and calculated values when the ratio of the strengths of the phases was greater than four.

The working introduced into the composite materials raised the compressive strength level in all combinations tested. With the exception of the composite containing the Al-Cu eutectic, this may be attributed, in part, to the work hardening of the metals. The working performed on the Al-Cu eutectic composite was carried out at a temperature well above the recrystallization point of the aluminum matrix, and therefore, this cannot be responsible for the increase. It is believed that the substantial increase in strength obtained with this composite is associated with some bonding between the components of the composite in conjunction with the diffusion of copper into the aluminum matrix.

Another factor which may serve to increase the strengths of composites of this type may be associated with the reduction of the section thickness of the soft primary phase. It is believed that

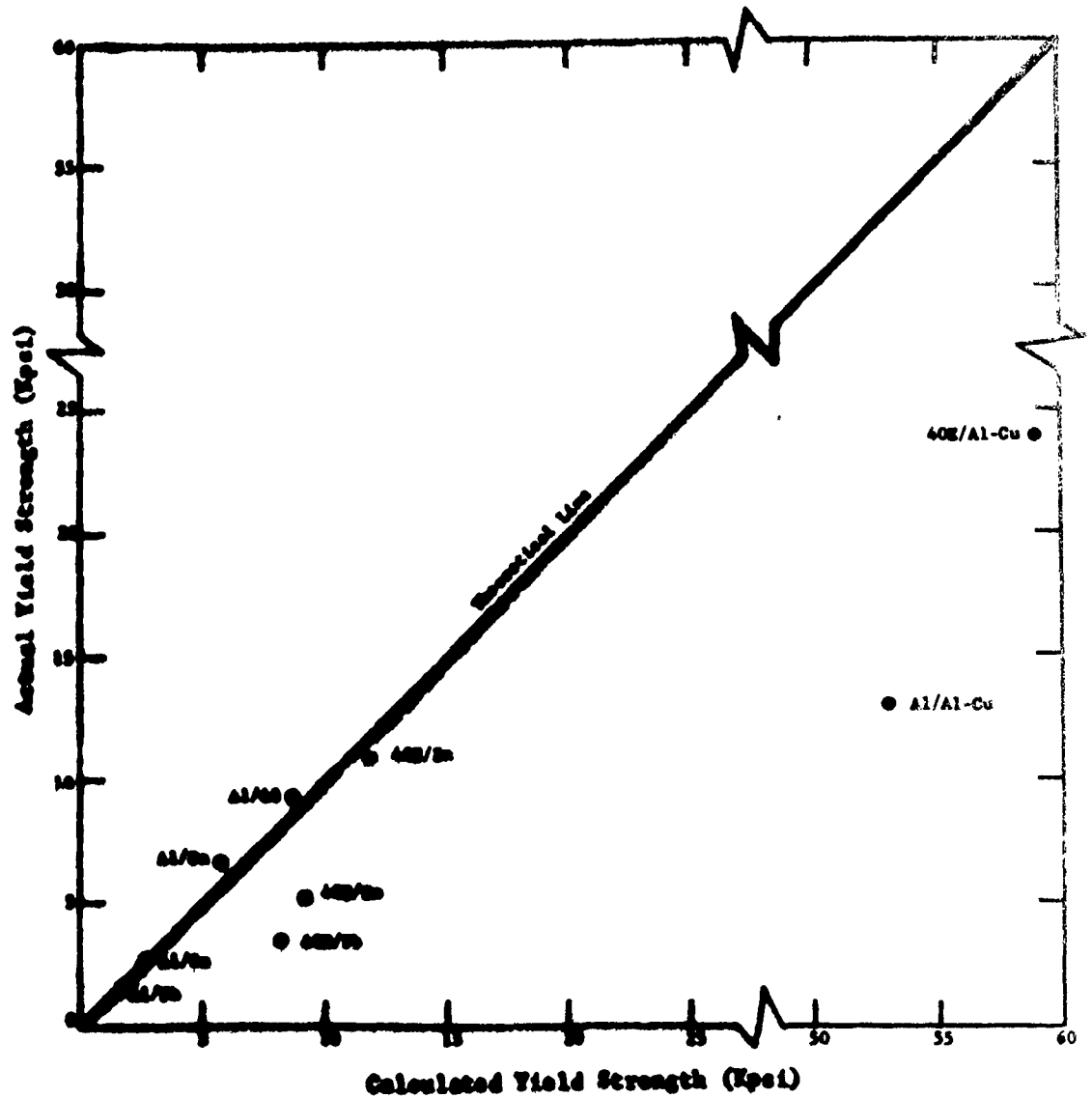


Figure 11. Calculated vs actual Compressive Yield Strength (0.2% offset) of Cast Metal-Metal Composites

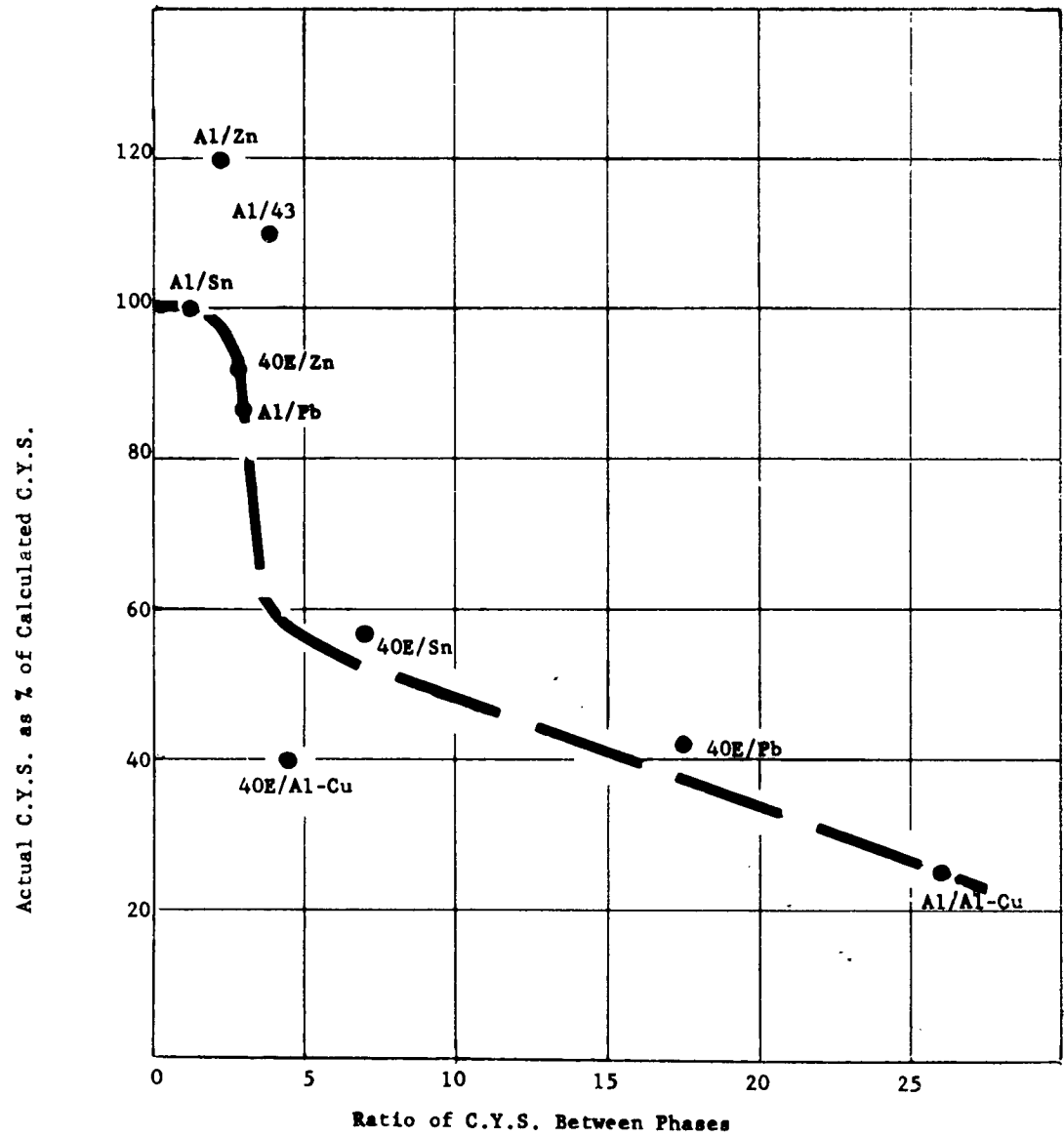


Figure 12. Realized Compressive Yield Strength (0.2% offset) as a percentage of the calculated Strength

this phase should be considered as analagous to the solder in a soldered joint. This phase should serve a similar purpose in the composite structure, viz., that of bonding the strong phase into a coherent structure. If the proper reduction ratios are selected in working the composite, the soft phase should be reduced sufficiently in section so that it will develop the same kind of joint strength pattern as is observed in soldered joints of progressively thinner section. As the joint thickness is reduced, the joint strength increases greatly. It is anticipated that this would be the case if the optimum working were introduced into these composites.

In addition to the aforementioned factors, it may be noted that an orientation of phases may serve to strengthen these composites in alignment with the direction of working.

Although the strength levels reached with the two component systems prepared in the course of this study are not impressive, the data do serve to indicate trends which ultimately may reach interesting levels. The solid Al-Cu eutectic developed a yield strength-to-density ratio of almost 700,000 inches. Assuming that the contribution of the phases in a two phase system should be proportionate to the volumes present, the 2S Al/Al-Cu eutectic composite should develop a strength-to-density ratio of approximately 460,000 inches. The actual values obtained for this composite is only 25 percent of the potential strength of the material. Working of this composite resulted in doubling the strength-to-density ratio. It is anticipated that improved working practice and proper selection of the composite phases should produce a substantial increase in the strengths of these composites. This extrapolation is based upon the thin bond phenomenon noted previously and upon the use of extrusion as a working technique. The extrusion studies of composites (described in Part II of this report) indicate that this method should be far superior to the forging and swaging methods employed in preparation of these samples. For example, the swaging techniques were totally inadequate for reduction of metal-salt composites. The extrusion experiments described in Part II of this report show that the antimonial lead-salt composite could be extruded with a 10:1 diameter reduction without difficulty. In view of the great difference in the characteristics of these two phases, the extrusion method promises to tolerate large differences in the properties of the component phases of the composites.

Future work will be concerned with the extrusion of composite systems and evaluation of the mechanical properties of the materials. Because of the strength potential indicated for composites which contain intermetallic compounds, the major effort will be directed toward the study of these materials.

PART II - EXTRUDED CELLULAR METAL

METHODS AND MATERIALS

The working of a cellular metal skeleton will result in compaction of the material and reduction in the void volume. In order to prevent closing of the voids during working, it is necessary to perform the working operation with the soluble component "in situ." The following working processes were examined as possible means for reduction of composite metal-salt billets: (a) rolling; (b) swaging; and (c) extrusion. Test billets prepared for the first two methods were sheathed with solid aluminum envelopes in an attempt to avoid break-up of the composite during reduction. The material resulting from both of these processing procedures was unsatisfactory. This was attributed to the lack of sufficient constraint during working, which permitted break-up to occur.

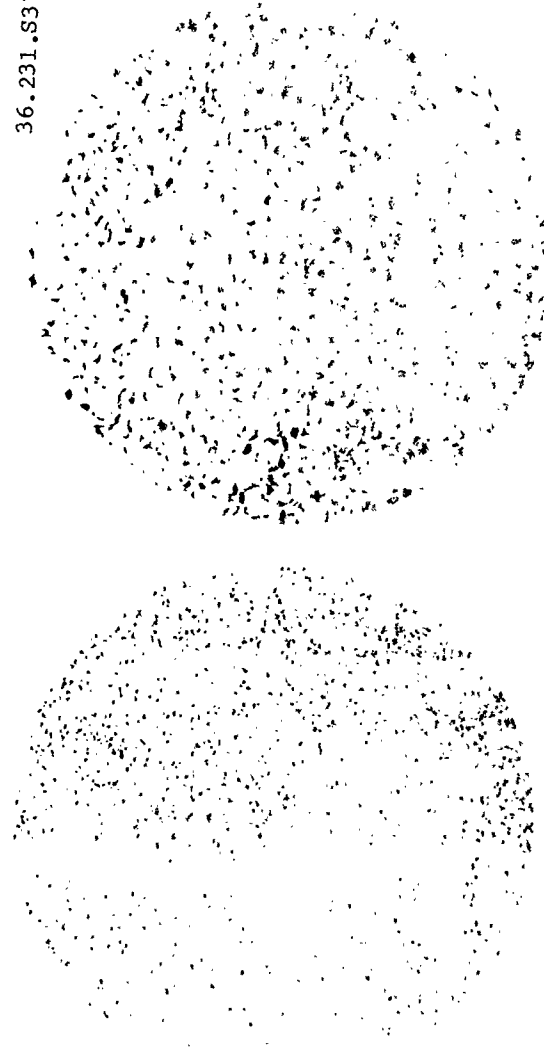
The extrusion process appeared to offer the degree of constraint for the material that was thought to be necessary. Since a hot extrusion facility, necessary for aluminum, was not available at Frankford Arsenal, it was decided to employ a model of the system to test its feasibility. Lead-salt composite billets were prepared and extruded through a 0.50-inch diameter die. A Watson-Stilman press, used to extrude antimonial lead bullet core stock, was used for this purpose.

Extrusion Procedure

Three billets were prepared for these tests. Figure 13 shows leached sections of two of these billets. The metal is 9 percent antimonial lead, the billets are 4.5 inches in diameter by 5 inches long, and the average cell diameters are 0.093 inch and 0.033 inch. The third billet was prepared in a manner identical to that represented by the coarser cell material except that pure lead was used.

The extrusion press had its cylinder oriented vertically and the extrusion direction was downward. A conical die was inserted in front of the extrusion die to promote proportional reduction of the billet cross-section. This apparently was effective since the thin solid skin which surrounded the billet section was transferred to the extruded rod. Figure 14 shows a partially extruded billet which was removed from the press. The salt was leached (Appendix) to more clearly show the flow pattern.

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Cell diameter, 0.033 in.

Cell diameter, 0.093 in.

Cell diameter, 0.093 in.

Figure 13. Sections of Cellular Antimonial Lead Material

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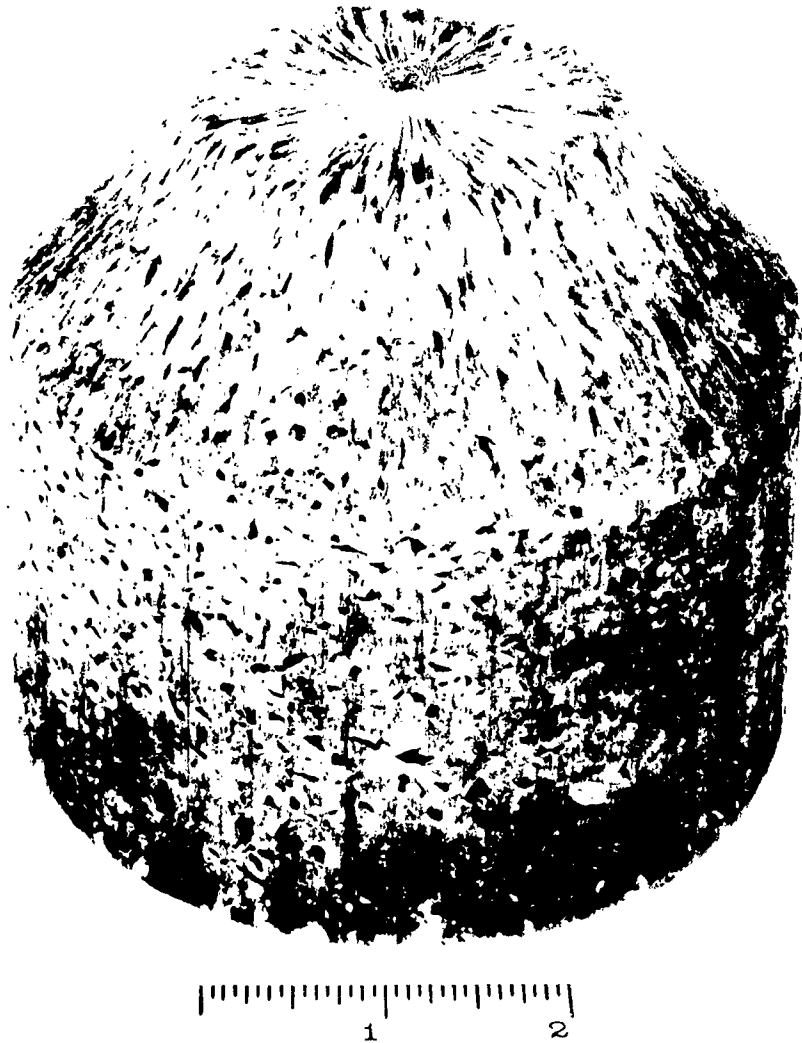


Figure 14. Partially extruded Cellular Aluminum Billet

Extrusion was begun with material and dies at room temperature. At a pressure of 800 tons (40 tons/in.²), which happened to be the limit of the press capacity, the composite material began to move slowly through the die. As extrusion proceeded, the rate increased due to heat generated in the billet and die during extrusion. The extruded material was removed from the press as short lengths of rod. The extrusion fractured into these lengths because of the sharp radius of the guide tube used to carry the extruded metal away from the die orifice. It was not possible to eliminate the guide tube because the vertical orientation of the press required a sharp radius to bring the extruded stock away from the base of the machine. It was apparent, however, that were a horizontal press used, extruded rods of any desired length could have been obtained. When the pure lead-salt composite was extruded, the material began to move at a pressure of 500 tons (25 tons/in.²). The extrusion, however, was unsatisfactory. It appeared that the salt composite fractured during the process.

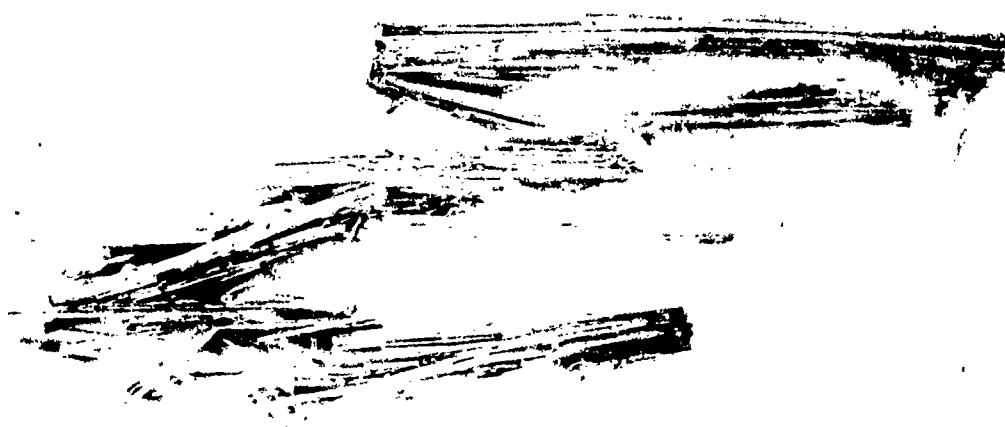
Examination of the Extrusions

Visual examination of the extrusions revealed that the composites which contained the 9 percent antimonial lead did not suffer from any signs of break-up during processing. The edge revealed a large number of cells through the section and was further evidence that the composite deformed as a unit. The pure lead sample, however, behaved differently in the press. It appeared that the salt crystals fractured during extrusion and were carried through embedded as fragments in the lead matrix. In addition, many surface imperfections appeared on the extruded rod.

In order to make a visual examination of the condition of the salt component after extrusion, the metal component was melted away with a torch, exposing the salt. This confirmed the observations made on the extrusion itself. The salt contained in the antimonial lead composites showed evidence of having been plastically deformed during extrusion and was recovered as bundles of fine filaments. Figure 15 shows a typical example of the condition of the salt after extrusion. The salt contained in the pure lead composite was present in the form of fragments which were not much smaller than that contained in the extrusion billet.

Qualitative evaluation of the leaching characteristics of these extrusions indicated that leaching proceeded more rapidly than with the as-cast material. This was thought to be due to the fact that, for the most part, each cell extended the full length of the sample.

36.231.S0570/ORD.62



Mag: Approx 3X

Figure 15. Salt filaments recovered from extruded Antimonial Lead
(9 percent Sb)-NaCl Composite Rod

This means that there were no restricted passages such as are encountered in leaching as-cast material. It is believed that the passages which connect the individual cells with one another are chiefly responsible for the slower leaching rates observed with equiaxed metal-salt composites.

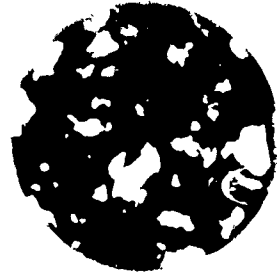
If it is assumed that the extruded billets are proportionately reduced during extrusion, the cell dimensions of the extruded material can be predicted on the basis of the cell dimensions of the extrusion billet. The cross-sectional area of the cell in the extruded material is reduced by a factor which is the square of the reduction ratio. In the case of a 9:1 diameter reduction, the sectional area of the cell in the extruded material is 81 times smaller than that of the billet. In order to account for the full volume of material contained in the original cell, the extruded cell must be 81 times longer than that of the cell in the billet. Its length in relation to the diameter of the cells in the extruded rod is $r^3 d_e$, where r is the reduction ratio and d_e is the cell diameter in the extrusion. Measurements made on the filaments recovered from the extruded material confirmed the hypothesis that the billet reduction was proportional throughout its entire section. The dimensions of these filaments very closely agreed with those computed from the original cell size. Figure 16 shows radiographs of 1/8 inch thick sections taken from the extruded rod. It can be clearly seen that the structure which is characteristic of the billet (9 percent Sb) has been carried through to the extruded rod. The pure lead sample, however, confirms that deformation of the salt did not occur and that it is present as fragments of the original aggregate.

DISCUSSION

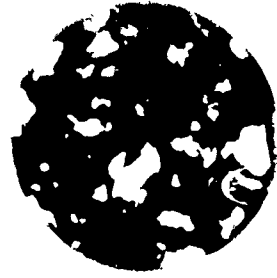
The scope of these experiments with extrusion of metal-salt composites was limited due to lack of hot extrusion facilities. The results, however, indicate that the extrusion process can be useful for fabrication of cellular metal. It has been demonstrated that metal-salt composite billets can be extruded into rod and that the salt component of the system will behave as a ductile material if the pressures are adequate. Other metal-salt systems should lend themselves to the same kind of processing by control of extrusion temperature, which is, in effect, a means for control of the pressure applied to the metal.

Practical applications of this processing can be discussed only on a speculative basis at this point. The process may find application for manufacture of the following types of items.

36.231.S3688/ORD.61



Antimonial Lead



Pure Lead

Figure 16. Positives of radiographs of transverse sections of Lead-Salt Composites
Mag: 6X

Filters

By control of the cell size of the billet and the extrusion ratio, it should be possible to economically produce extruded cellular stock of aluminum base alloys having highly directionally oriented cells of accurately controlled cross-section. This stock could be sliced and leached to form disc filters. Filters of this type should be much superior to currently available types because the directionality of the pores or cells would correspond exactly with the direction of flow. This would minimize pressure drop through the filter and would permit the manufacture of filter discs having any desired characteristic for the exclusion of undesirable particles. For example, a billet prepared with 100-mesh soluble aggregate, reduced ten diameters by extrusion, would have cells which are 0.015 mm (0.0006 inch) in diameter and 15 mm (0.6 inch) long. A disc 0.2 inch thick cut from this extrusion would have two-thirds of its cells run completely through the section.

Heat Exchanger Tubes

Tube bundles of the type used for heat exchange applications could be conveniently fabricated by this technique providing the tube lengths required are not excessive. An extrusion billet prepared with a solid skin representing 5 percent of its diameter and containing 2-inch diameter aggregate, could be reduced ten diameters by extrusion. This would result in extruded rod which would, in effect, be a bundle of tubes, each 0.2 inch in diameter, and would run for 2,000 inches in length. The tube bundle would be sheathed in a solid skin representing 5 percent of its diameter. It should be feasible to leach rods several feet in length to form the tube bundles. An eight-foot rod produced under these conditions would have 95 percent of its cells run the complete length of the rod.

Ultrafine Wire Manufacture

The same extrusion process used to produce the long cellular structure should be amenable to the manufacture of ultrafine wire. This could be done by using the metal phase as aggregate and preparing a salt-metal composite extrusion billet. This application may be visualized as a bundle of copper wires completely embedded longitudinally in a salt matrix. If the wires are 0.010 inch in diameter and the extrusion ratio is twenty, the wire diameter would be reduced to 0.0005 inch and each wire would be drawn out to 400 times its original length. The wires could be recovered from the extruded rod by leaching and spooling the wire as the surface strands are freed by the leaching liquor. This technique could be applied not only to round wire, but also wire that is square, oval, or any other desired shape.

APPENDIX

LEACHING NOTE

An improved method for leaching the metal-salt composite has been developed. A billet (0.83 mm cell size), 11 cm diameter by 11.5 cm long, was submerged in a 4000-ml beaker of water in accordance with practice described in the earlier report. The billet occupied a volume of 1090 cc containing 1120 gm of metal and 1450 gm of salt. The water was deaerated by vacuuming before the beaker was placed in a steam autoclave. The pressure was raised to 20 psi and maintained at this level for 30 minutes. The steam was then turned off and the autoclave allowed to return to atmospheric pressure. Approximately 3000 ml of liquid were recovered and found to have reached a salt concentration of approximately 25 percent, representing 900 gm of salt. The procedure was repeated and this time the liquid reached a concentration of 15% NaCl, representing an additional 500 gm of salt, accounting for substantially all of the salt originally present in the billet. The metal was then rinsed and dried. It weighed 1100 gm, confirming that all of the salt had been removed.

This treatment did not result in any discernable corrosion of the metal, which always occurred when other leaching techniques were used for a billet of this size. In addition, the leaching was accomplished in less than 10 percent of the time formerly required.

It is believed that the more rapid leaching is due to the following factors. Increased solubility of the salt at the higher temperatures results in a greater density of the liquid immediately adjacent to the salt, producing more active concentration currents as the denser, salt-laden liquid settles to the bottom of the container. The deaeration of the water, together with the steam atmosphere, results in an oxygen-free environment, greatly minimizing corrosion of the metal. This corrosion is ordinarily the chief source for the generation of gas bubbles which limit access of the leaching liquid to the salt. Finally, the diffusion process, which is the chief mechanism for movement of the salt in confined areas of the billet, proceeds at a greatly accelerated rate due to the elevation of the temperature of the system.

This benefit can only be realized to advantage because of the favorable environment. Prior experience has shown that elevation of the temperature without exclusion of oxygen simply increases corrosion rates, generates more gas bubbles, and greatly slows the leaching process.

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